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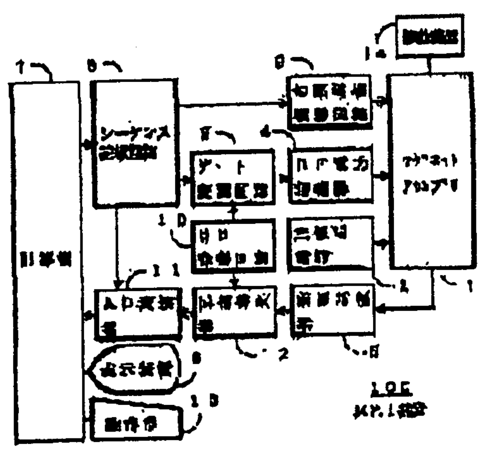
(54) MR IMAGING AND MRI SYSTEM

(57)Abstract:

PURPOSE: To provide an MR imaging method and an MRI system capable of photographing a moving object and imaging by suppressing an artifact, by calculating phase correction quantity from the mutual relation of each view data for navigation and phase-correcting the each view data for imaging by the phase correction quantity.



CONSTITUTION: By a magnet assembly 1 in an MRI system 100, firstly, imaging echoes are sampled via a phase detector 12, etc., while applying a phase encode gradient onto the y axis and a frequency encode gradient onto the x axis, respectively, to collect each view data for imaging. Secondly, a rewind gradient is applied to return the phase encode quantity to '0', and, while applying the encode gradient and the read-out gradient of the sampling number of which polarity is reversed, data for navigation in the frequ ncy axis direction is c ll cted by sampling

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(54) Title of the Invention: MR imaging method and MRI device

(57) Summary (amended)

Problem: To suppress artifacts when imaging a moving object for imaging.

Configuration: While applying a phase-encoding gradient pe along the y-axis and a frequency-encoding gradient ri along the x-axis, the image echo IE is sampled, and p-view imaging data is collected. Then, a rewind gradient pr is applied and the phase encoding amount is returned to "0", and while applying a sampling number readout gradient rn1 with polarity opposite the encoding gradient ri, the navigation echo NE1 is sampled, and navigation data is collected in the frequency-axis direction corresponding to p-view imaging data. This is repeated while changing the gradients pe and pr, to collect data for M views and for navigation. Phase correction amounts are computed from the

interrelation of navigation data for each view, imaging data for each view is phase-corrected, and images are reconstructed from this data.

Claims

Claim 1: An MR imaging method, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in that

at least two echoes are generated for one RF pulse, the phase encoding amount for one echo is set to "0", navigation data SRp(f') in the frequency-axis direction in the p view for data number f' ($-N'/2 \leq f' \leq N'/2-1$) is collected while applying a readout gradient for N' samples along the frequency axis, phase-encoding is added and frequency-encoding is added to the remaining echoes corresponding to the k-space p view, collection by this means of imaging data D'(f,p) for the p view in k-space is repeated, imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view is collected, from the interrelation of navigation data for each view $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$, phase correction amounts $\Delta\phi x(p)$ are calculated, and using these phase correction amounts $\Delta\phi x(p)$, imaging data for each view D'(f,p) is phase-corrected.

Claim 2: An MR imaging method, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in that

at least two echoes are generated for one RF pulse, the frequency encoding amount for one echo is set to "0", navigation data SWp(p') in the phase-axis direction in the p view for data number p' ($-M'/2 \leq p' \leq M'/2-1$) is collected while applying a readout gradient for M' samples along the phase axis, phase-encoding is added and frequency-encoding is added to the remaining echoes corresponding to the k-space p view, collection by this means of imaging data D'(f,p) for the p view in k-space is repeated, imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view is collected, from the interrelation of navigation data for each view $SW_{-M/2}(p')$ to $SW_{M/2-1}(p')$, phase correction amounts $\Delta\phi y(p)$ are calculated, and using these phase correction amounts $\Delta\phi y(p)$, imaging data for each view D'(f,p) is phase-corrected.

Claim 3: An MRI device, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in comprising:

data collection means, which generates at least two echoes for one RF pulse, setting the phase encoding amount for one echo to "0", collects navigation data SRp(f') in the frequency-axis direction in the p view for data number f' ($-N'/2 \leq f' \leq N'/2-1$) while applying a readout gradient for N' samples along the frequency axis, adds phase encoding and adds frequency encoding to the remaining echoes corresponding to the k-space p

view, repeats collection by this means of imaging data D'(f,p) for the p view in k-space, and collects imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view; and,

phase correction means, which, from the interrelation of navigation data for each view $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$, calculates phase correction amounts $\Delta\phi x(p)$, and using these phase correction amounts $\Delta\phi x(p)$, phase-corrects imaging data for each view D'(f,p).

Claim 4: An MRI device, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in comprising:

data collection means, which generates at least two echoes for one RF pulse, setting the frequency encoding amount for one echo to "0", collects navigation data SWp(p') in the phase-axis direction in the p view for data number p' ($-M'/2 \leq p' \leq M'/2-1$) while applying a readout gradient for M' samples along the phase axis, adds phase encoding and adds frequency encoding to the remaining echoes corresponding to the k-space p view, repeats collection by this means of imaging data D'(f,p) for the p view in k-space, and collects imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view; and,

phase correction means, which, from the interrelation of navigation data for each view $SW_{-M/2}(p')$ to $SW_{M/2-1}(p')$, calculates phase correction amounts $\Delta\phi y(p)$, and using these phase correction amounts $\Delta\phi y(p)$, phase-corrects imaging data for each view D'(f,p).

Claim 5: An MRI device, comprising:

data collection means, which sets the encoding amount of the first encoding axis of k-space to "0", and while applying a readout gradient along the second encoding axis of k-space, collects navigation data S1, and then similarly collects navigation data S2; and,

movement amount calculation means, which calculates movement amounts Δ of the signal source for a direction in real space corresponding to said second encoding axis from the interrelation between the projection profile determined from the absolute value of the first-order Fourier transform of said navigation data S1, and the projection profile determined from the absolute value of the first-order Fourier transform of said navigation data S2.

Detailed Description of the Invention

0001

Industrial Field of the Invention

This invention relates to an MR (magnetic resonance) imaging method and an MRI (magnetic resonance imaging) device. More specifically, it relates to an MR imaging method and MRI device which image a moving object for imaging, and which can perform imaging with artifacts suppressed.

0002

Prior Art

Fig. 14 shows a schematic diagram of one example of an MRI device of the prior art. In this MRI device 500, 50 is the imaging device, 50a is the bore, and 60 is a cradle which moves the object for imaging G. 51 is a movement-stopping control unit which stops the cradle 60 during imaging. In this MRI device 500, movement of the object for imaging G is stopped, imaging is performed, and a first image of length T in the movement direction is obtained. Then, after movement by a distance T, [the object for imaging] is again stopped and imaging performed, to obtain a second image of length T in the movement direction. This is repeated n times, and by joining the n images obtained, from the first to the nth, an image of length nT is obtained. The above MRI device 500 is, for example, disclosed in Japanese Patent Laid-open No. 63-272335.

0003

Problem to be Solved by the Invention

In the above MRI device 500 of the prior art, when imaging is performed using the imaging device 50, the cradle 60 is stopped, and when the cradle 60 is used to move the object for imaging G, the imaging device 50 is stopped. Hence there is the problem that the imaging efficiency is poor. One object of this invention is to provide an MR imaging method and MRI device capable of imaging a moving object for imaging, and performing imaging with artifacts suppressed.

0004

Means to Solve the Problem

In a first aspect, this invention provides an MR imaging method, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in that at least two echoes are generated for one RF pulse, the phase encoding amount for one echo is set to "0", navigation data SRp(f') in the frequency-axis direction in the p view for data number f' ($-N'/2 \leq f' \leq N'/2-1$) is collected while applying a readout gradient for N' samples along the frequency axis, phase-encoding is added and frequency-encoding is added to the remaining echoes corresponding to the k-space p view, collection by this means of imaging data D'(f,p) for the p view in k-space is repeated, imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view is collected, from the interrelation of navigation data for each view $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$, phase correction amounts $\Delta\phi x(p)$ are calculated, and using these phase correction amounts $\Delta\phi x(p)$, imaging data for each view D'(f,p) is phase-corrected.

0005

In a second aspect, this invention provides an MR imaging method, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is

repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in that at least two echoes are generated for one RF pulse, the frequency encoding amount for one echo is set to "0", navigation data SWp(p') in the phase-axis direction in the p view for data number p' ($-M'/2 \leq p' \leq M'/2-1$) is collected while applying a readout gradient for M' samples along the phase axis, phase-encoding is added and frequency-encoding is added to the remaining echoes corresponding to the k-space p view, collection by this means of imaging data D'(f,p) for the p view in k-space is repeated, imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view is collected, from the interrelation of navigation data for each view $SW_{-M/2}(p')$ to $SW_{M/2-1}(p')$, phase correction amounts $\Delta\phi y(p)$ are calculated, and using these phase correction amounts $\Delta\phi y(p)$, imaging data for each view D'(f,p) is phase-corrected.

0006

In a third aspect, this invention provides an MRI device, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in comprising data collection means, which generates at least two echoes for one RF pulse, setting the phase encoding amount for one echo to "0", collects navigation data SRp(f') in the frequency-axis direction in the p view for data number f' ($-N'/2 \leq f' \leq N'/2-1$) while applying a readout gradient for N' samples along the frequency axis, adds phase encoding and adds frequency encoding to the remaining echoes corresponding to the k-space p view, repeats collection by this means of imaging data D'(f,p) for the p view in k-space, and collects imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view; and, phase correction means, which, from the interrelation of navigation data for each view $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$, calculates phase correction amounts $\Delta\phi x(p)$, and using these phase correction amounts $\Delta\phi x(p)$, phase-corrects imaging data for each view D'(f,p).

0007

In a fourth aspect, this invention provides an MRI device, in which, when k-space frequency-axis data numbers are f ($-N/2 \leq f \leq N/2-1$) and phase-axis data numbers are p ($-M/2 \leq p \leq M/2-1$), an RF pulse is added, phase encoding is added, and frequency encoding is added, and collection of imaging data D'(f,p) from echoes which appear is repeated, to collect imaging data D'(f,-M/2) to D'(f,M/2-1) sufficient for an M view, and characterized in comprising data collection means, which generates at least two echoes for one RF pulse, setting the frequency encoding amount for one echo to "0", collects navigation data SWp(p') in the phase-axis direction in the p view for data number p' ($-M'/2 \leq p' \leq M'/2-1$) while applying a readout gradient for M' samples along the phase axis, adds phase encoding and adds frequency encoding to the remaining echoes corresponding to the k-space p view, repeats collection by this means of imaging data D'(f,p) for the p view in k-space, and collects imaging data D'(f, -M/2) to D'(f, M/2-1) for an M view; and phase correction means, which, from the interrelation of navigation data for each view

$SW_{-M/2}(p')$ to $SW_{M/2-1}(p')$, calculates phase correction amounts $\Delta\phi y(p)$, and using these phase correction amounts $\Delta\phi y(p)$, phase-corrects imaging data for each view $D'(f,p)$.

0008

In a fifth aspect, this invention provides an MRI device [Translator's note: Original erroneously reads "an MR imaging method"], comprising data collection means, which sets the encoding amount of the first encoding axis of k-space to "0", and while applying a readout gradient along the second encoding axis of k-space, collects navigation data S1, and then similarly collects navigation data S2; and, movement amount calculation means, which calculates movement amounts Δ of the signal source for a direction in real space corresponding to said second encoding axis from the interrelation between the projection profile determined from the absolute value of the first-order Fourier transform of said navigation data S1, and the projection profile determined from the absolute value of the first-order Fourier transform of said navigation data S2.

0009

Action

As shown in Fig. 12, when there is a signal source g(x,y) in the real space region (x,y), $-Fw/2 \le x \le Fw/2$, $-Pw/2 \le y \le Pw/2$, the data D(f,p) collected in k-space is as given by the following equation. Here the x-axis direction is the frequency-axis direction, and the y-axis direction is the phase-axis direction. (The y-axis and x-axis are axes in real space corresponding to either the phase axis or the frequency axis. On the other hand, the Z-axis, Y-axis, and X-axis of the gradient magnetic field coil, described below, are axes in real space which specify the construction of the magnet assembly 1.)

0010

Equation 1

$$D(f,p)=\int_{-\frac{Pw}{2}}^{\frac{Pw}{2}}\int_{-\frac{Pw}{2}}^{\frac{Pw}{2}} g(x,y)\cdot e^{-j\frac{2\pi f}{Pw}x}\,dx\cdot e^{-j\frac{2\pi p}{Pw}y}\,dy$$

f is the frequency axis data number, $-N/2 \le f \le N/2-1$.

p is the phase axis data number, $-M/2 \le p \le M/2-1$.

0011

Next, as shown in Fig. 13, if the case is considered in which the above signal source g(x,y) moves by an amount Δx in the x-axis direction, then the data D'(f,p) collected in k-space is given by the following equation.

0012

Equation 2

$$D'(f,p)=\int_{-\frac{Pw}{2}}^{\frac{Pw}{2}}\int_{-\frac{Fw}{2}}^{\frac{Fw}{2}} g(x-\Delta x,\ y)\cdot e^{-j\frac{2\pi f}{Fw}x}dx\cdot e^{-j\frac{2\pi p}{Pw}y}dy$$

0013

Here, if X=x-Δx, then eq. (2) becomes as follows.

0014

Equation 3

$$\begin{aligned} D'(f,p) &= \int_{-\frac{Pw}{2}}^{\frac{Pw}{2}}\int_{-\frac{Fw}{2}-\Delta x}^{\frac{Fw}{2}-\Delta x} g(X,y)\cdot e^{-j\frac{2\pi f}{Fw}(X+\Delta x)}dX\cdot e^{-j\frac{2\pi p}{Pw}y}dy \\ &= e^{-j\frac{2\pi f}{Fw}\Delta x}\int_{-\frac{Pw}{2}}^{\frac{Pw}{2}}\int_{-\frac{Fw}{2}-\Delta x}^{\frac{Fw}{2}-\Delta x} g(X,y)\cdot e^{-j\frac{2\pi f}{Fw}X}dX\cdot e^{-j\frac{2\pi p}{Pw}y}dy \\ &= e^{-j\frac{2\pi f}{Fw}\Delta x}\cdot D(f,p) \end{aligned}$$

0015

From eq. (3), if phase correction is performed on the data D'(f,p),

$$D(f,p) = \exp\{j2\pi f\Delta x/Fw\} \times D'(f,p)$$

and the two-dimensional Fourier transform is taken, the imaging is seen to be equivalent to the case in which the signal source g(x,y) is not moving, as shown in Fig. 13. Here, if the movement amount Δx is different for each view, then using the movement amount Δxp for each view, phase-correction is performed for the data D'(f,p) of all views using

$$D(f,p) = \exp\{j2\pi f\Delta xp/Fw\} \times D'(f,p) \qquad \ldots\ldots (4)$$

and by taking the two-dimensional Fourier transform of the data D(f,p) obtained, an image is obtained which is equivalent to the case in which the signal source g(x,y) is not moving. That is, image pickup of the moving object for imaging is performed, and imaging is possible while suppressing artifacts.

0016

In the case where the above signal source g(x,y) moves by Δyp in the y-axis direction, similarly to the above, using

$$D(f,p) = \exp\{j2\pi p\Delta yp/Pw\} \times D'(f,p) \qquad \ldots\ldots (5)$$

phase correction is performed for the data D'(f,p) for all views, and by taking the two-dimensional Fourier transform for the obtained data D(f,p), an image is obtained equivalent to the case in which the signal source g(x,y) is not moving.

0017

In the case where the above signal source g(x,y) moves by Δxp in the x-axis direction, and moves by Δyp in the y-axis direction, similarly to the above, by using

$$D(f,p) = \exp\{j2\pi(f\Delta xp/Fw + p\Delta yp/Pw)\} \times D'(f,p) \quad \ldots\ldots (6)$$

phase correction can be performed for the data D'(f,p) of all views, and by taking the two-dimensional Fourier transform of the data obtained D(f,p), an image is obtained equivalent to the case in which the signal source g(x,y) is not moving.

0018

In the MR imaging method of the above first aspect and the MRI device of the above third aspect, at least two echoes are generated for one RF pulse. Of these, the phase encoding amount for one echo is set to "0", and while applying a readout gradient with N' samples along the frequency axis, navigation data SRp(f') for the frequency-axis direction in the p view of data number f' ($-N'/2 \leq f' \leq N'/2-1$) is collected. Phase-encoding is added, and frequency-encoding is added, to the remaining echoes corresponding to the k-space p view, and by this means data D'(f,p) for imaging of the p view in k-space is collected in order. The phase correction amount $\Delta\phi x(p)$ is calculated from the interrelation of navigation data SRp(f') for each view, and the imaging data D'(f,p) is phase-corrected for each view using the phase correction amount $\Delta\phi x(p)$. The above navigation data SRp(f') is collected with the phase encoding amount always at "0", so that from the interrelation, the movement amount Δxp in the x-axis direction of the signal source in each view can be determined. Here, if $2\pi f\Delta xp/Fw = \Delta\phi x(p)$, then the above eq. (4) is obtained, and on taking the two-dimensional Fourier transform of the data D(f,p) obtained from phase correction, an image is obtained equivalent to the case in which the signal source g(x,y) is not moving. That is, image pickup of the object for imaging moving in the x-axis direction is performed, and imaging is possible with artifacts suppressed.

0019

In the MR imaging method of the above second aspect and the MRI device of the above fourth aspect, at least two echoes are generated for one RF pulse. Of these, the frequency encoding amount for one echo is set to "0", and while applying a readout gradient with M' samples along the phase axis, navigation data SWp(p') for the phase-axis direction in the p view of data number p' ($-M'/2 \leq p' \leq M'/2-1$) is collected. Phase-encoding is added, and frequency-encoding is added, to the remaining echoes corresponding to the k-space p view, and by this means data D'(f,p) for imaging of the p view in k-space is collected in order. The phase correction amount $\Delta\phi y(p)$ is calculated from the interrelation of navigation data SWp(p') for each view, and the imaging data D'(f,p) is phase-corrected for each view using the phase correction amount $\Delta\phi y(p)$. The above navigation data SWp(p') is collected with the frequency encoding amount always at "0", so that from the interrelation, the movement amount Δyp in the y-axis direction of the signal source in each view can be determined. Here, if $2\pi p\Delta yp/Pw = \Delta\phi y(p)$, then the above eq. (5) is obtained, and on taking the two-dimensional Fourier transform of the data D(f,p) obtained from phase correction, an image is obtained equivalent to the case in which the signal source g(x,y) is not moving. That is, image pickup of the object for imaging moving in the y-axis direction is performed, and imaging is possible with artifacts suppressed.

0020

As a configuration of a combination of the above configurations, at least three echoes are generated for one RF pulse. Of these, the phase encoding amount for one echo is set to "0", and while applying a readout gradient with N' samples along the frequency axis, navigation data SRp(f') is collected for the frequency-axis direction in the p view for data number f' ($-N'/2 \le f' \le N'/2-1$). For another echo, the frequency encoding amount is set to "0", and while applying a readout gradient with M' samples along the phase axis, navigation data SWp(p') is collected for the phase-axis direction in the p view for data number p' ($-M'/2 \le p' \le M'/2-1$). For the remaining echoes, phase encoding and frequency encoding are added according to the p view in k-space, and by this means imaging data D'(f,p) for p views in k-space is collected in order. From the interrelations between navigation data SRp(f') for each view, the phase correction amount $\Delta\phi x(p)$ is calculated, from the interrelations between navigation data SWp(p') for each view, the phase correction amount $\Delta\phi y(p)$ is calculated, and the phase correction amounts $\Delta\phi x(p)$, $\Delta\phi y(p)$ are used to phase-correct the imaging data D'(f,p) for each view. The above navigation data SRp(f') is always collected for a phase encoding amount of "0", so that from this interrelation, the movement amount Δxp in the x-axis direction of the signal source can be determined for each view. The above navigation data SWp(p') is always collected with the frequency encoding amount at "0", so that from the interrelation, the movement amount Δyp in the y-axis direction of the signal source can be determined for each view. Here, if it is assumed that

$$2\pi f\Delta xp/Fw = \Delta\phi x(p)$$

$$2\pi p\Delta yp/Pw = \Delta\phi y(p)$$

then the above eq. (6) is obtained, and by taking the two-dimensional Fourier transform of the data D(f,p) obtained by phase correction, an image is obtained which is equivalent to the case in which the signal source g(x,y) is not moving. That is, image pickup of the object for imaging, which moves in the x-axis and y-axis directions, is performed, and imaging is possible while suppressing artifacts.

0021

In the MRI device of the above fifth aspect, the encoding amount of the first encoding axis in k-space is set to "0", and while applying a readout gradient along the second encoding axis in k-space, navigation data S1 is collected. Then, navigation data S2 is similarly collected. From the interrelation between the projection profile determined from the absolute value of the one-dimensional Fourier transform of the above navigation data S1, and the projection profile determined from the absolute value of the one-dimensional Fourier transform of the above navigation data S2, the amount of movement Δ of the signal source in the direction in real space corresponding to the above second encoding axis is calculated. The above projection profiles reflect the position of the signal source in real space, and so the variable value resulting in a maximum in the cross-correlation function represents the shift in position. Hence from this, the movement amount Δ of the signal source is found.

0022

Embodiments

Below, this invention is explained in further detail, based on the embodiments shown in the drawings. This does not limit the scope of the present invention.

0023

First Embodiment

The first embodiment is an embodiment in which, if the axis in real space corresponding to the frequency-axis direction in k-space is the x axis, the axis in real space corresponding to the phase-axis direction in k-space is the y axis, and the axis in real space with which the x-axis and y-axis are orthogonal is the z-axis, then the direction of movement of the object for imaging is the x-axis direction.

0024

Fig. 1 is a block diagram of the first embodiment of the MRI device of this invention. In this MRI device 100, the magnet assembly 1 has a bore (hole) for insertion of the object for imaging (not shown) into the interior; surrounding this bore is a static magnetic field coil which applies a uniform static magnetic field to the object for imaging, a gradient magnetic field coil which generates a gradient magnetic field (the gradient magnetic field coil comprises orthogonal Z-axis, Y-axis, and X-axis coils), a transmission coil to apply RF pulses which excite the spins of atomic nuclei in the object for imaging, and a reception coil which detects the NMR (nuclear magnetic resonance) signal from the object for imaging. The static magnetic field coil, gradient magnetic field coils, transmission coil and reception coil are connected to the main magnetic field power supply 2, gradient magnetic field driving circuit 3, RF power amplifier 4, and preamp 5, respectively.

0025

The sequence storage circuit 8 operates the gradient magnetic field driving circuit 3 based on a stored pulse sequence, according to instructions from the computer 7, causing a gradient magnetic field to be generated from the gradient magnetic field coils of the above magnet assembly 1, and also operates the gate modulation circuit 9, modulating carrier-wave output signals from the RF generator circuit 10 by pulse signals with a prescribed timing and prescribed envelope shape; these are applied to the RF power amplifier 4 as RF pulses, and after power amplification by the RF power amplifier 4, [the pulses] are applied to the transmission coil of the above magnet assembly 1, to excite the target region of the object for imaging.

0026

The preamp 5 amplifies NMR signals from the object for imaging detected by the reception coil of the magnet assembly 1, and inputs [the signals] to the phase detector 12. The phase detector 12 performs phase detection of the NMR signals from the preamp 5, taking the carrier-wave output signals from the RF generator circuit 10 as reference signals, and applies the result to the A/D converter 11. The A/D converter 11 converts the phase-detected analog signals into digital signals, for input to the computer 7. The computer 7 performs image reconstruction processing on the digital signals from the A/D

converter 11, and generates an image of the target region of the object for imaging. This image is displayed on the display device 6. The computer 7 also handles general control such as receipt of information input from an operation console 13.

0027

The object for imaging is placed on the movement device 14, which transports the object for imaging into the bore of the above magnet assembly 1.

0028

The above sequence storage circuit 8 stores a pulse sequence used to execute the MR imaging method of this invention. The above computer 7 collects imaging data and navigation data based on the pulse sequence for execution of the MR imaging method of this invention, performs phase-correction of imaging data based on the navigation data, performs image reconstruction processing of the phase-corrected imaging data, and generates an image of the target region of the object for imaging.

0029

Fig. 2 is a pulse sequence for the case in which the object for imaging is moved in the x-axis direction during image pickup. In this pulse sequence A, an RF pulse Rα with flip angle α° is applied, and a slice gradient ss is also applied along the z-axis. Next, a phase-encoding gradient pe is applied along the y-axis. Then, while applying a frequency-encoding gradient ri along the x-axis, the image echo IE arising at time TE1 after the above RF pulse Rα is sampled, and p-view imaging data D'(f,p) is collected. Next, a rewind gradient pr is applied, and the phase encoding amount is returned to "0". Then, while applying a readout gradient rnl with N' samples, with polarity inverted from the above frequency-encoding gradient ri, the navigation echo NE1 appearing at time TE2 after the above RF pulse Rα is sampled, and navigation data SRp(f') corresponding to the p-view imaging data D'(f,p) is collected. This is repeated M times with repetition time TR, while changing the phase-encoding gradient pe and rewind gradient pr, to collect the imaging data D'(f,-M/2) to D'(f,M/2-1) for an M view, and the corresponding M-view navigation data $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$. In Fig. 2, dp is a dephase gradient, and cr is a crush gradient.

0030

In Fig. 3, (a) is a schematic diagram showing the relation between the imaging data D'(f,-M/2) in k-space and the navigation data $SR_{-M/2}(f')$ when p=-M/2. In Fig. 3, (b) is a schematic diagram showing the relation between the imaging data D'(f,-M/2+1) in k-space and the navigation data $SR_{-M/2+1}(f')$ when p=-M/2+1.

0031

Fig. 4 is a flowchart of the processing for phase-correction of imaging data D'(f,p) based on the above navigation data SRp(f'). In step V1, initialization to the view number counter p=-M/2 is performed. In step V2, navigation data SRo(f') corresponding to the 0 view is multiplied with the conjugate SRp*(f') of the p-view navigation data SRp(f'). That is, ZRp(f') = SRp (f') · SRo(f') is calculated.

0032

In step V3, the one-dimensional Fourier transform of the product ZRp(f') is taken, and the cross-correlation function zrp(x) is found. Fig. 5 shows a cross-correlation function. The cross-correlation function zrp(x) is the cross-correlation function of the projection profile sro(x) determined from the absolute value of the one-dimensional Fourier transform of the navigation data SRo(f'), and the projection profile srp(x) determined from the absolute value of the one-dimensional Fourier transform of the navigation data SRp(f') (correlation theorem).

0033

Returning to Fig. 4, in step V4, approximating interpolation using the least-squares method is employed to determine the variable value Δxp yielding the maximum value of the cross-correlation function zrp(x). In step V5, the phase-correction amount $\Delta\phi x(p)$ is calculated from $2\pi f\Delta xp/Fw = \Delta\phi x(p)$, and the imaging data D'(f,p) is multiplied by $\exp\{j\Delta\phi x(p)\}$ to obtain p-view phase-corrected imaging data D(f,p). In steps V6 and V7, the above steps V2 to V5 are executed iteratively from $p=-M/2+1$ to $p=M/2-1$, to acquire imaging data D(f,p) for all views in k-space.

0034

By reconstructing the image from the above phase-corrected imaging data D(f,p) to generate the image, even if image pickup is performed while continuously moving the object for imaging in the x-axis direction, a high-quality image can be obtained with reduced motion artifacts.

0035

Second Embodiment

The second embodiment is an embodiment in which, if the axis in real space corresponding to the frequency-axis direction in k-space is the x axis, the axis in real space corresponding to the phase-axis direction in k-space is the y axis, and the axis in real space with which the x-axis and y-axis are orthogonal is the z-axis, then the direction of movement of the object for imaging is the y-axis direction. A block diagram of the MRI device is similar to Fig. 1.

0036

Fig. 6 is a pulse sequence for the case in which the object for imaging is moved in the y-axis direction during image pickup. In this pulse sequence B, an RF pulse $R\alpha$ with flip angle $\alpha°$ is applied, and a slice gradient ss is also applied along the z-axis. Next, a phase-encoding gradient pe is applied along the y-axis. Then, while applying a frequency-encoding gradient ri along the x-axis, the image echo IE arising at time TE1 after the above RF pulse $R\alpha$ is sampled, and p-view imaging data D'(f,p) is collected. Next, a rewind gradient pr is applied, and the phase encoding amount is returned to "0". Also, a rephase gradient rp, with polarity inverted from the above frequency-encoding gradient ri, is applied, and the frequency-encoding amount is returned to "0". Next, while applying a dephase gradient dp and readout gradient rn2 with M' samples to the phase axis (y-axis), the navigation echo NE2 appearing at time TE3 after the above RF pulse $R\alpha$ is sampled,

and navigation data SWp(p') corresponding to the p-view imaging data D'(f,p) is collected. This is repeated M times with repetition time TR, while changing the phase-encoding gradient pe and rewind gradient pr, to collect the imaging data D'(f,-M/2) to D'(f,M/2-1) for an M view and the M-view navigation data $SW_{-M/2}(f')$ to $SW_{M/2-1}(f')$ corresponding to this. In Fig. 7, (a) is a schematic diagram showing the relation between the imaging data D'(f,-M/2) in k-space and the navigation data $SW_{-M/2}(f')$ when p=-M/2. (b) in Fig. 7 is a schematic diagram showing the relation between the imaging data D'(f,-M/2+1) in k-space and the navigation data $SW_{-M/2+1}(f')$ when p=-M/2+1.

0037

Fig. 8 is a flowchart of the processing for phase correction of imaging data D'(f,p) based on the above navigation data SWp(p'). In step U1, initialization to the view number counter p=-M/2 is performed. In step U2, navigation data Swo(p') corresponding to the 0 view, and the conjugate Swp*(p') of the p-view navigation data SWp(p'), are multiplied. That is, ZWp(p') = SWp*(p') · SWo(p') is calculated.

0038

In step U3, the one-dimensional Fourier transform of the product ZWp(p') is taken, to determine the cross-correlation function zwp(y). Fig. 9 shows the cross-correlation function zwp(y). The cross-correlation function zwp(y) is the cross-correlation function between the projection profile swo(y) determined from the absolute value of the one-dimensional Fourier transform of the navigation data SWo(p'), and the projection profile srp(y) determined from the absolute value of the one-dimensional Fourier transform of the navigation data SWp(p') (correlation theorem).

0039

Returning to Fig. 8, in step U4, approximating interpolation using the least-squares method is employed to determine the variable value Δyp yielding the maximum value of the cross-correlation function zwp(y). In step U5, the phase-correction amount Δϕy(p) is calculated from 2πpΔyp/Pw = Δϕy(p), and the imaging data D'(f,p) is multiplied by exp{jΔϕy(p)} to obtain p-view phase-corrected imaging data D(f,p). In steps U6 and U7, the above steps U2 to U5 are executed iteratively from p=-M/2+1 to p=M/2-1, to acquire imaging data D(f,p) for all views in k-space.

0040

By reconstructing the image from the above phase-corrected imaging data D(f,p) to generate the image, even if image pickup is performed while continuously moving the object for imaging in the y-axis direction, a high-quality image can be obtained with reduced motion artifacts.

0041

Third Embodiment

The third embodiment is an embodiment in which, if the axis in real space corresponding to the frequency-axis direction in k-space is the x axis, the axis in real space corresponding to the phase-axis direction in k-space is the y axis, and the axis in real

space with which the x-axis and y-axis are orthogonal is the z-axis, then the directions of movement of the object for imaging are the x-axis and y-axis directions. A block diagram of the MRI device is similar to Fig. 1.

0042

Fig. 10 is a pulse sequence for the case in which the object for imaging is moved in the x-axis and y-axis directions during image pickup. In this pulse sequence C, an RF pulse $R\alpha$ with flip angle $\alpha°$ is applied, and a slice gradient ss is also applied along the z-axis. Next, a phase-encoding gradient pe is applied along the y-axis. Then, while applying a frequency-encoding gradient ri along the x-axis, the image echo IE arising at time TE1 after the above RF pulse $R\alpha$ is sampled, and p-view imaging data D'(f,p) is collected. Next, a rewind gradient pr is applied, and the phase encoding amount is returned to "0". Then, while applying a readout gradient rnl with N' samples, with polarity inverted from the above frequency-encoding gradient ri, the navigation echo NE1 appearing at time TE2 after the above RF pulse $R\alpha$ is sampled, and navigation data SRp(f') corresponding to the p-view imaging data D'(f,p) is collected. Next, a rephase gradient rp with polarity inverted from the above frequency-encoding gradient rnl is applied, and the frequency encoding amount is returned to "0". Also, while applying a dephase gradient dp and readout gradient rn2 with M' samples along the phase axis (y axis), the navigation echo NE2 appearing at time TE3 after the above RF pulse $R\alpha$ is sampled, and navigation data SWp(p') corresponding to the p-view imaging data D'(f,p) is collected. This is repeated M times with repetition time TR, while changing the phase-encoding gradient pe and rewind gradient pr, to collect the imaging data D'(f,-M/2) to D'(f,M/2-1) for an M view, and the corresponding M-view navigation data $SR_{-M/2}(f')$ to $SR_{M/2-1}(f')$ and navigation data $SW_{-M/2}(f')$ to $SW_{M/2-1}(f')$. Fig. 11 is a flowchart of processing for phase correction of the imaging data D'(f,p) based on the above navigation data SRp(f') and SWp(p'). In step S1, initialization to the view number counter p=-M/2 is performed. In step S2, navigation data SRo(f') corresponding to the 0 view is multiplied by the conjugate SRp*(f') of the p-view navigation data SRp(f'). That is, ZRp(f') = SRp*(f') · SRo(f') is calculated. In step S3, the one-dimensional Fourier transform of the product ZRp(f') is taken, and the cross-correlation function zrp(x) is determined. In step S4, approximating interpolation using the least-squares method is employed to determine the variable value Δxp yielding the maximum value of the cross-correlation function zrp(x).

0043

In step S5, the navigation data SWo(p') corresponding to the 0 view, and the conjugate SWp*(p') of the p-view navigation data SWp(p'), are multiplied. That is, ZWp(p') = SWp*(p') · SWo(p') is calculated. In step S6, the one-dimensional Fourier transform of the product ZWp(p') is taken, and the cross-correlation function zwp(y) is determined. In step S7, approximating interpolation using the least-squares method is employed to determine the variable value Δyp yielding the maximum value of the cross-correlation function zwp(y). In step S8, the phase-correction amount $\Delta\phi x(p)$ is calculated from $2\pi f\Delta xp/Fw = \Delta\phi x(p)$, the phase-correction amount $\Delta\phi y(p)$ is calculated from $2\pi p\Delta yp/Pw = \Delta\phi y(p)$, and the imaging data D'(f,p) is multiplied by $\exp\{j(\Delta\phi x(p)+\Delta\phi y(p))\}$ to obtain p-view phase-corrected imaging data D(f,p). In steps S9 and S10, the above steps S2 to

S8 are executed iteratively from p=-M/2+1 to p=M/2-1, to acquire imaging data D(f,p) for all views in k-space.

0044

By reconstructing the image from the above phase-corrected imaging data D(f,p) to generate the image, even if image pickup is performed while moving the object for imaging in the x-axis and y-axis directions, a high-quality image can be obtained with reduced motion artifacts.

0045

Other Embodiments

In the first through third embodiments, pulse sequences in the gradient echo method were explained, but [this invention] is not thereby limited; for example, a pulse sequence may be used in which a rewind gradient, and a readout gradient to read the navigation echo NE, are added to a spin-echo method pulse sequence.

0046

Further, in the first through the third embodiments, variable values yielding the maximum value of a cross-correlation function were determined by the least-squares method; however, the Lagrange interpolation method, Chebyshev interpolation method, Hanning interpolation method, cubic interpolation method, or other method may be used to determine the variable value yielding the maximum value of the cross-correlation function.

0047

Further, in the first through the third embodiments, the correlation theorem was used to calculate phase correction amounts; however, phase correction amounts may also be calculated from changes in the center of gravity of the projection profile determined from the absolute value of the one-dimensional Fourier transform of navigation data, or from changes in rise/fall positions.

0048

Advantageous Results

By means of the MR imaging method and MRI device of this invention, image pickup of a moving object for imaging is possible, and imaging can be performed with artifacts suppressed. Hence image pickup can be performed while continuously moving the object for imaging, and high-quality images can be obtained, so that the efficiency of image pickup can be improved.

Brief Description of the Drawings

Fig. 1 Schematic diagram of one embodiment of an MRI device of this invention

Fig. 2 Pulse sequence diagram for image pickup while moving the object for imaging in the x-axis direction

Fig. 3 Conceptual diagram showing the relation between imaging data D'(f,p) and navigation data SRp(f') in k-space

Fig. 4 Flowchart of phase correction processing for image pickup while moving the object for imaging in the x-axis direction

Fig. 5 Conceptual diagram of the cross-correlation function for the case of image pickup while moving the object for imaging in the x-axis direction

Fig. 6 Pulse sequence diagram for image pickup while moving the object for imaging in the y-axis direction

Fig. 7 Conceptual diagram showing the relation between imaging data D'(f,p) and navigation data SWp(p') in k-space

Fig. 8 Flowchart of phase correction processing for image pickup while moving the object for imaging in the y-axis direction

Fig. 9 Conceptual diagram of the cross-correlation function for the case of image pickup while moving the object for imaging in the y-axis direction

Fig. 10 Pulse sequence diagram for image pickup while moving the object for imaging in the x-axis and y-axis directions

Fig. 11 Flowchart of phase correction processing for image pickup while moving the object for imaging in the x-axis and y-axis directions

Fig. 12 Conceptual diagram of stationary signal source and k-space

Fig. 13 Conceptual diagram of signal source moving in the x-axis direction and k-space

Fig. 14 Schematic diagram of an example of a conventional MRI device

Explanation of Symbols

100	MRI device
1	Magnet assembly
3	Gradient magnetic field driving circuit
7	Computer
8	Sequence storage circuit
14	Movement device
IE	Image echo
NE	Navigation echo

Figure 1

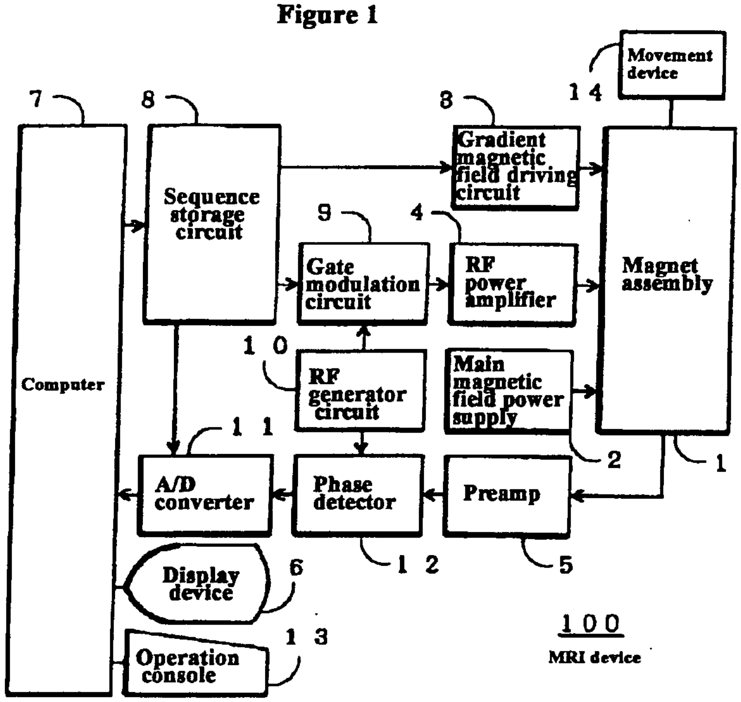


Figure 12

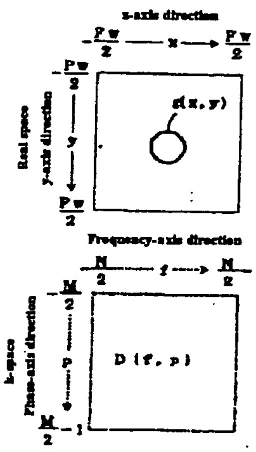


Figure 2

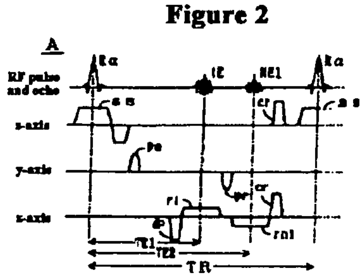


Figure 5

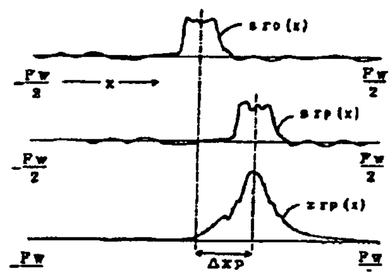


Figure 3

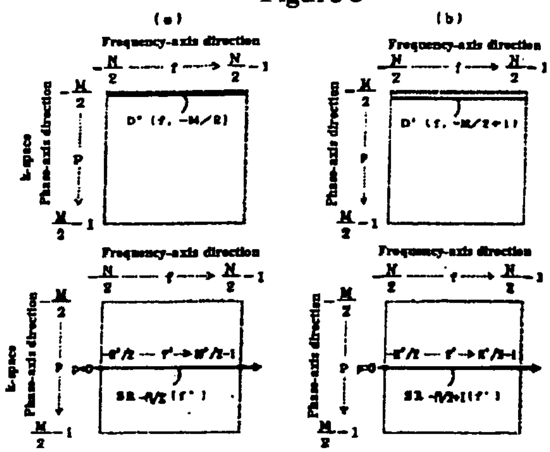


Figure 6

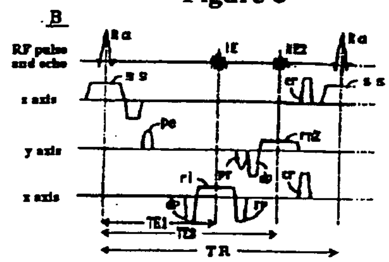


Figure 4

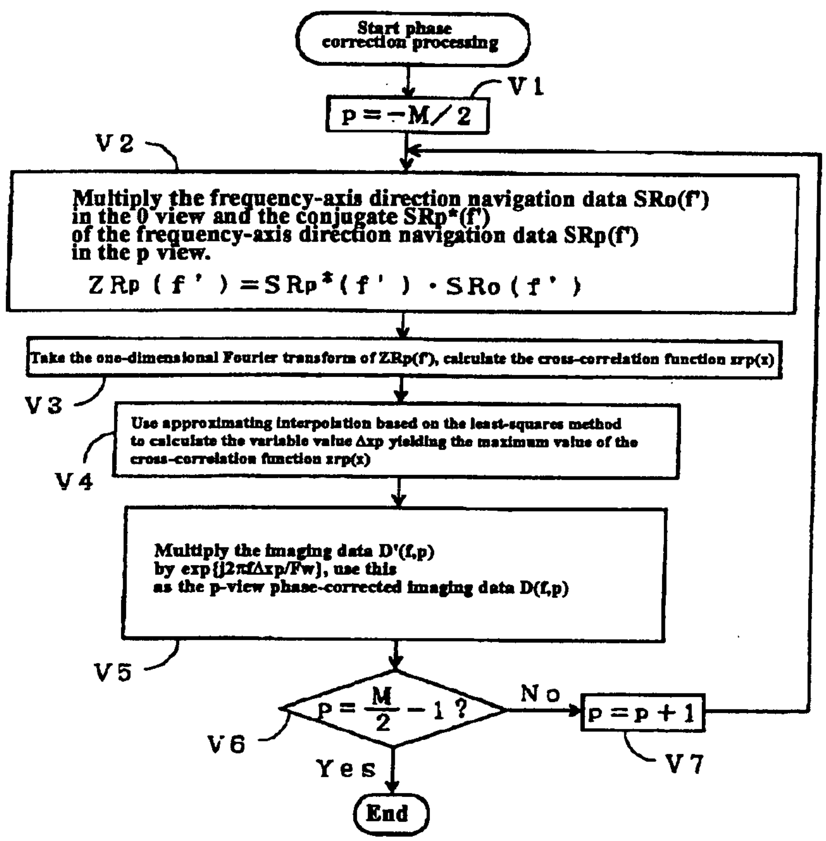


Figure 7

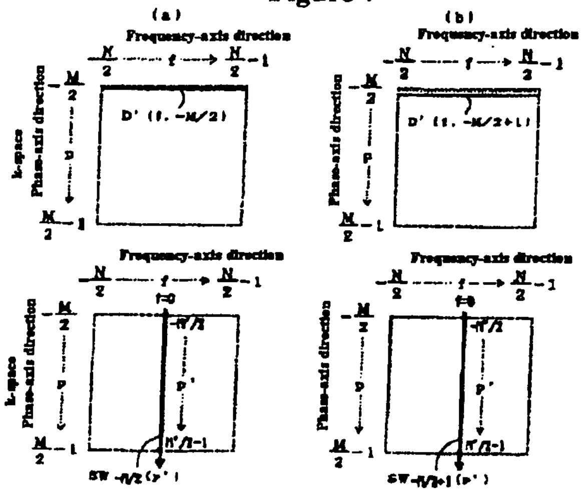


Figure 9

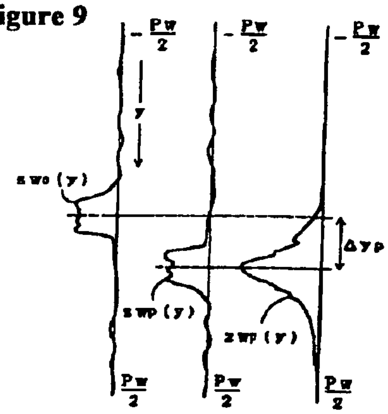


Figure 8

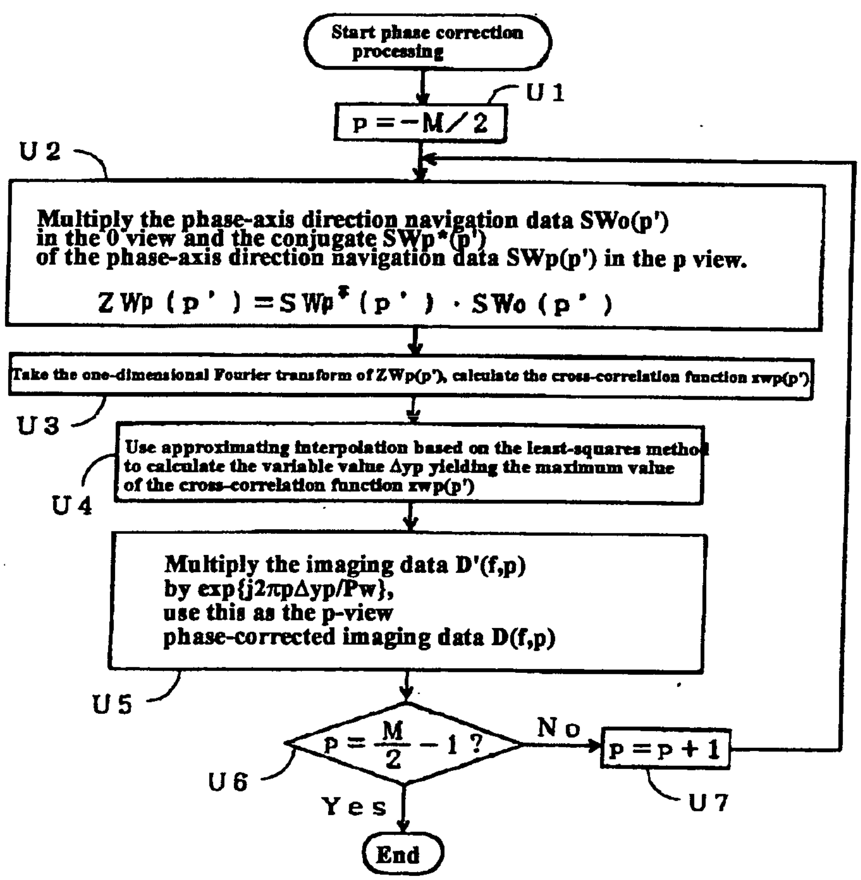


Figure 10

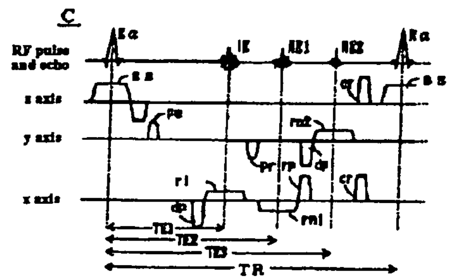


Figure 13

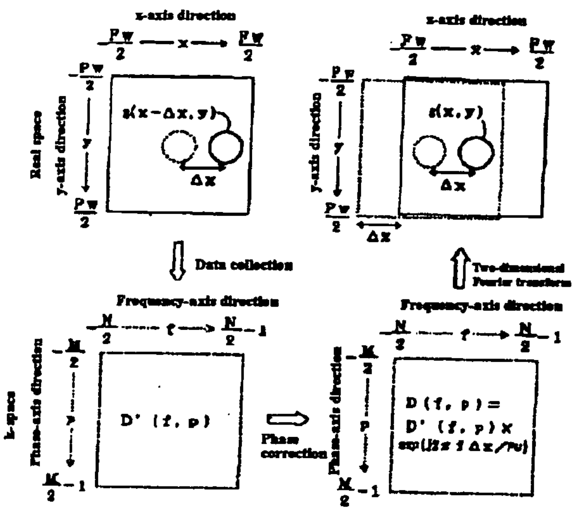


Figure 14

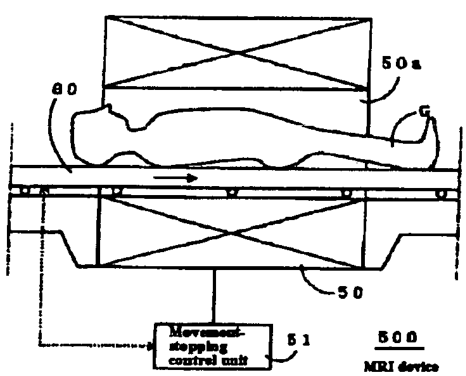
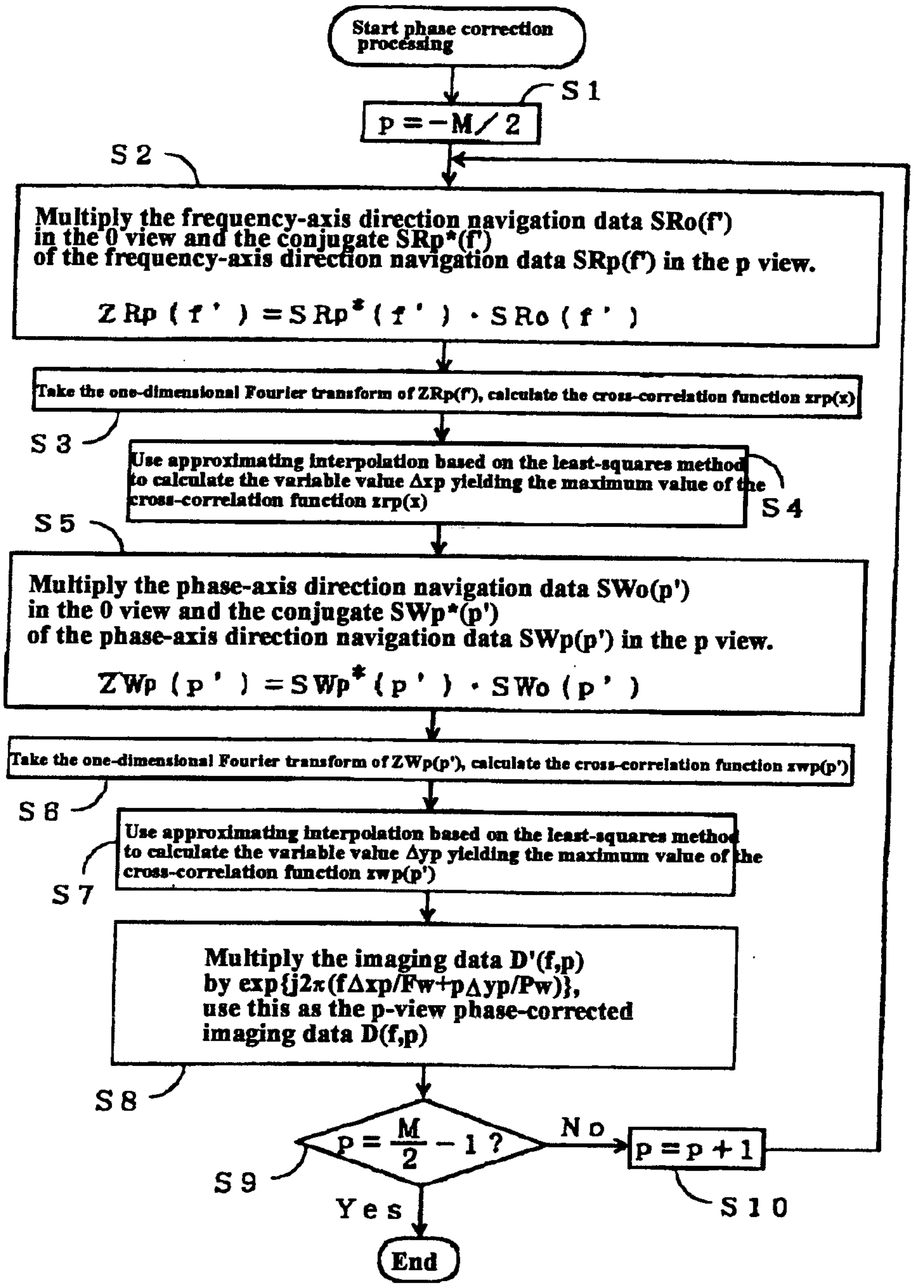


Figure 11


Start phase correction processing
S1
p = −M／2
S2
Multiply the frequency-axis direction navigation data SRo(f') in the 0 view and the conjugate SRp*(f') of the frequency-axis direction navigation data SRp(f') in the p view.
ZRp(f') = SRp*(f') · SRo(f')
Take the one-dimensional Fourier transform of ZRp(f'), calculate the cross-correlation function xrp(x)
S3
Use approximating interpolation based on the least-squares method to calculate the variable value Δxp yielding the maximum value of the cross-correlation function xrp(x)
S4
S5
Multiply the phase-axis direction navigation data SWo(p') in the 0 view and the conjugate SWp*(p') of the phase-axis direction navigation data SWp(p') in the p view.
ZWp(p') = SWp*(p') · SWo(p')
Take the one-dimensional Fourier transform of ZWp(p'), calculate the cross-correlation function xwp(p')
S6
Use approximating interpolation based on the least-squares method to calculate the variable value Δyp yielding the maximum value of the cross-correlation function xwp(p')
S7
Multiply the imaging data D'(f,p) by exp{j2π(fΔxp/Fw+pΔyp/Pw)}, use this as the p-view phase-corrected imaging data D(f,p)
S8
p = M/2 − 1 ?
No
p = p + 1
S9
Yes
S10
End